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Variability in the Granulometric Characteristic of a Tropical River-Estuary-Near Shore Ecosystem from its Source to Sink, Southwest Coast of India

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Abstract

The granulometric characteristics of surface sediment samples collected from the river, estuary and nearshore to perceive its variation from the source to sink was carried in the present study. Folk and Ward classification outline slightly gravelly sand to muddy gravelly sand, clay to muddy sand and sand for the environments. The study draws a distinction between transportation, deposition and hydrodynamic condition of the environments as depicted by the statistical parameters along with hydrodynamic condition, CM pattern (Coarser one percentile value in micron) and Linear Discriminate Functions (LDF).

Keywords: Estuary-Nearshore environment, Grain size analysis, CM pattern, LDF, Hydrodynamic condition

INTRODUCTION

The grain size analysis is one of the important and widely used sedimentological tools to unravel the hydrodynamic conditions of an aquatic environment. It also deals with properties of sediment discharge and depositional environment (Folk and Ward, 1964). Several factors that played a significant role in textural attributes are source area composition climate, length, and energy of sediment transport, sediment aggregation, sediment deposition, gravitation circulation, redox condition in the depositional media, etc (Fralick et al.,1997). Many exceptional donations have been made by renowned

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scientist worldwide into the nature and significance of grain-size distributions. They used statistical parameters like mean, standard deviation, skewness and kurtosis have been used effectively to understand the mechanism of transport and deposition. These properties are related to the energy of transporting media and it differentiates various depositional environments of recent and ancient sediments (Sahu,1964; Passega, 1964; Moiola, and Weiser,1968; Ganesh, et al., 2013; Mir, and Jeelani, 2015; Oyedotun , 2016 and Zarczynski et al., 2019). An endeavor has been made here to study the particle size distribution of sediments from three different environments to understand the hydrodynamic processes.

MATERIALS AND METHODS

Surface sediment samples were collected from the river (Yasin et al., 2016), estuary (Thomas, and Baba 1986) and 14 samples from the near shore up to a depth of 20m using van Veen grab. The samples were weighed and subjected to textural analysis outlined by (Folk, and Ward, 1957). The samples containing a significant amount of silt and clay were subjected to sieving and pipetting as suggested by (Carver, 1971). The grain size parameters such as mean size, median, mode, standard deviation, skewness, and kurtosis were calculated (Folk, and Ward, 1957). CM pattern (Passega, 1957) and LDF (Sahu, 1964) were used to decipher the depositional environment.

STUDY AREA

The study area (fig 1) includes Vamanapuram River originates from Chemmungi mottai in the Western Ghats at a height of about 1717 m above mean sea level. The river has a length of 88Km and drainage area of 687 sq km. The river flows through highland, midland and low land covering 34 panchayats and drains into the Akathumuri-Anchuthengu- Kadinamkulam (AAK) estuary near Chirayinkil in Thiruvananthapuram district and. The AAK estuary is almost parallel to adjoining Lakshadweep Sea and opens to the sea through an inlet at Muthalapozhi. The construction of breakwaters has caused a permanent opening to the sea for the estuary which was earlier seasonally connected with the Arabian Sea through the opening of the sandy bar. For rest of the year a temporary spit forms at the mouth rendering the estuary “blind’’. After the construction of breakwaters and due to dredging activities natural condition has changed and opened the way for continuous mixing of fresh and seawater. The Vamanapuram River is the only freshwater source of the estuary. The nearshore area extends from Neduganda – transect M1 to Thumba – transect M3, is a part of a high energy sandy coast. This 17 Km long coast has an average width of about 200 m and comprises the inner shelf zone up to 20 m isobaths. The seafloor is smooth, with an average seaward gradient of approximately 1:77 between the inshore area and 30 m isobaths.

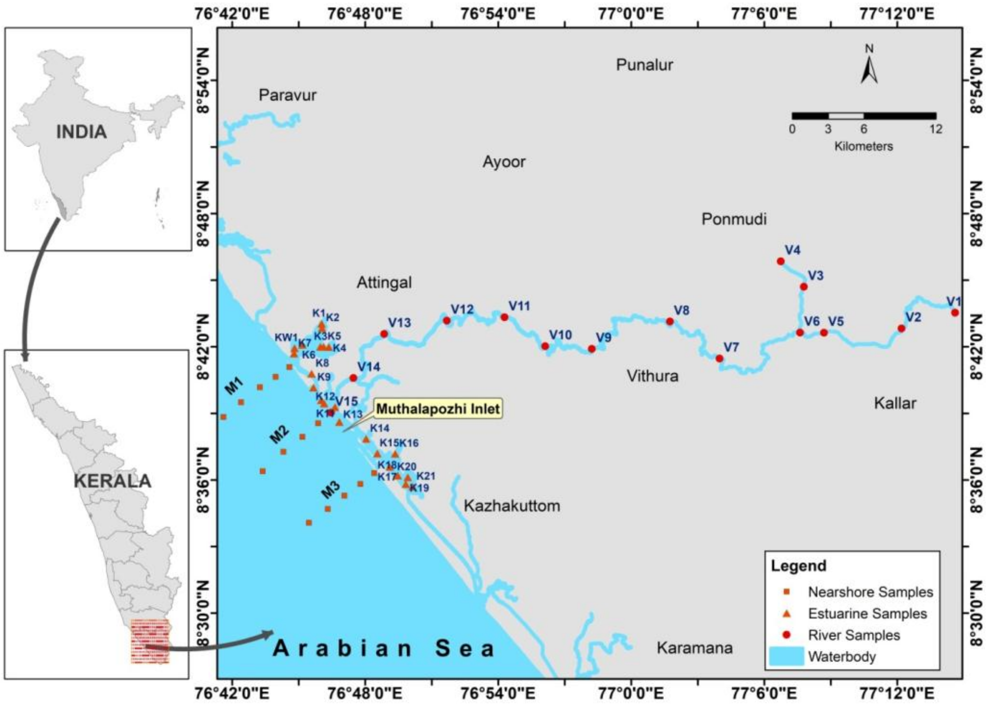


Figure 1. Study area map showing sampling locations

RESULT AND DISCUSSION

The results of grain size analysis of the three environments are presented in the table 1. The Vamanapuram River exhibits a continuum of particle sizes series from pebbles to mud, while bigger particles like cobbles and boulders are expelled from the present study because of the difficulty in measuring size classes. The river sediments are characterized by a high amount of pebbles in the upper stream reaches and it radically vanishes as the river enters the midland. The average percentage of pebbles was 4.8 with the highest percentage noticed in the Kallar region (V5) from where the river reduces its competency and starts flowing through the midland region of the study area. River sediments are marked by a high amount of granules throughout its course, having an average percentage of 14.9. The average sand fraction is 69.6 % and it clearly evident that every fraction of sand shows a similar trend downstream. As the river enters the estuary the grain size varies from very coarse sand to very fine sand. Very fine sand contributed the highest average of 10.4% followed by medium sand 8%, fine sand 6.3%, coarse sand 3.5% and very coarse sand 0.5%. In the estuarine samples, clay contributed the highest percentage which an average of 41.7% and silt showed a similar trend as that of sand with an average of 29.6%. The Muthalapozhi nearshore region is mainly carpeted with very coarse sand with an average value of 97.6 % and was found in the order M3> M2> M1. The average silt and clay percentage are 0.74 % and 1.24 % respectively. According to Folk and Ward (1970) classification, the sediments of the river ranged from slightly gravelly sand to muddy gravelly sand, clay to muddy sand for the estuary and sand for the nearshore sediments (fig 2)

Table 1. Percentage of various grain size fractions in sediments of (a) Vamanapuram River (b) AAK estuary and (c) Muthalapozhi near shore

(a) Vamanapuram River	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11	V12	V13	V14	Average
Pebble	0	20.7	16.8	24.93	0	0	0	0	0	0	0	0	0	4.8
Granule	52.9	6.6	25.7	7.72	5.4	6.5	24.2	38.9	0.3	7.6	0	16	2.2	14.9
Very Corse Sand	20.8	21.6	24.7	15	6.4	29.7	31	42.5	0.4	16.5	0.4	16.4	3.3	17.6
Corse Sand	13.1	21.1	12.7	16.6	14.8	32.3	18.7	9.7	7	29.5	2	13.8	6.1	15.2
Medium Sand	6.1	17	8.1	16.1	24.6	20.2	13.9	1.3	56.4	28.1	52.3	24.7	10.8	21.5
Fine Sand	0.9	4.3	1.6	5.4	28	3.5	3.7	0.4	17.9	8.7	21.6	10.5	26.5	10.2
Very Fine Sand	0.8	1.7	0.6	0.7	9.6	1.7	1.2	0.5	7.8	2.6	9.5	6.5	23.1	5.1
Total sand	41.7	65.7	47.7	53.8	83.4	87.4	68.5	54.4	89.5	85.4	85.8	71.9	69.8	69.6
Silt	1.4	2.9	6.9	9.8	4.2	2	3.3	2.3	3.8	2.4	4	3.8	18.3	5.0
Clay	4.1	4.2	2.9	3.9	6.9	4.2	4	4.4	6.4	4.5	10.1	8.2	9.6	5.6

(b) AAK Estuary

Grain size	K1	K2	K3	K4	K5	K6	K7	K8	K9	K10	K11	K12	K13	K14	K15	K16	K17	K18	K19	K20	K21	Average
Very Coarse Sand	0.10	0.4	0.70	0.3	0.00	0.00	0.10	0.40	0.50	2.50	3.70	0.10	0.70	0.10	0.10	0.2	0.0	0.1	0.3	0.1	0	**0.50**
Coarse Sand	0.10	0.2	0.5	2.2	0.00	0.10	1.90	3.50	5.40	34.00	18.10	0.50	3.40	0.50	0.20	0.1	0.2	0.4	0.8	0.7	1.2	**3.52**
Medium Sand	0.10	0.2	0.2	8.20	0.20	0.50	10.80	18.20	18.80	43.70	28.70	1.40	12.60	4.20	0.20	0.1	0.6	1.5	1.6	6.4	10	**8.01**
Fine Sand	0.10	0.4	0.5	6.00	0.70	1.40	24.40	7.10	11.20	6.70	7.90	3.80	28.70	8.20	0.70	0.3	1.8	3.3	3.1	6.2	10.2	**6.32**
Very Fine Sand	0.20	0.3	0.7	4.90	3.00	2.00	38.00	11.00	5.30	3.40	12.20	10.30	39.50	61.50	10.50	1.0	1.8	2.0	2.2	4.8	3.5	**10.39**
Total Sand	0.60	1.5	2.6	21.60	3.90	4.00	75.20	40.20	41.20	90.30	70.60	16.10	84.90	74.50	11.70	1.7	4.4	7.3	8.0	18.2	24.9	**28.73**
Silt	49.00	9.2	19.7	19.20	53.90	38.80	17.80	21.40	54.30	6.20	11.60	30.60	10.30	10.90	42.60	61.9	29.4	21.7	20.0	53.0	39.5	**29.57**
Clay	50.40	89.3	77.7	59.20	42.10	57.20	6.90	38.20	4.60	3.60	17.40	53.20	4.80	14.70	45.60	36.5	66.2	70.9	72.1	29.8	35.7	**41.72**
Mud	99.40	98.5	97.4	78.40	96.00	96.00	24.70	59.60	58.90	9.80	29.00	83.80	15.10	25.60	88.20	98.4	95.6	92.6	92.1	82.8	75.2	**71.29**

(C) Muthalapozhi near shore	Grain size	Beach	5m	10m	15m	20m	Average
M1	Very Coarse sand	0.5	4.6	0	0.3	1.8	1.44
	Coarse sand	1.8	19.3	0.3	1.7	26.9	10
	Medium Sand	8.6	47.9	1.6	40.6	63.9	32.52
	Fine Sand	19.6	21.8	1.2	18.5	5.2	13.26
	Very fine sand	68.7	4.6	95.2	31.7	1.3	40.3
	Total sand	99.2	98.2	98.3	92.8	99.1	97.52
	Silt	0.7	0.8	1.3	1.3	0.6	0.94
	Clay	0.2	1	0.4	6	0.3	1.58
M2	Very Coarse sand	ND	0	0	0.5	2.8	0.83
	Coarse sand	ND	0.7	0.6	5.1	31.5	9.48
	Medium Sand	ND	25.8	9.1	69.2	54.1	39.55
	Fine Sand	ND	47.3	37	12.5	3.6	25.1
	Very fine sand	ND	25.3	50.9	10.5	4.2	22.73
	Total sand	ND	99.1	97.6	97.8	96.2	97.68
	Silt	ND	0.6	0.6	0.5	0.8	0.63
	Clay	ND	0.3	1.8	1.7	3.1	1.73
M3	Very Coarse sand	0.5	0.2	1.9	0.2	0.1	0.58
	Coarse sand	14.8	2.1	25.1	2.4	0.5	8.98
	Medium Sand	80.6	48.1	64.7	24.2	7	44.92
	Fine Sand	2.4	26.4	5.1	5.3	12.3	10.3
	Very fine sand	0.2	16.2	2.2	67	79	32.92
	Total sand	98.5	93	99	99.1	98.9	97.7
	Silt	0.5	0.5	0.8	0.6	0.8	0.64
	Clay	0.9	0.2	0.3	0.3	0.3	0.4

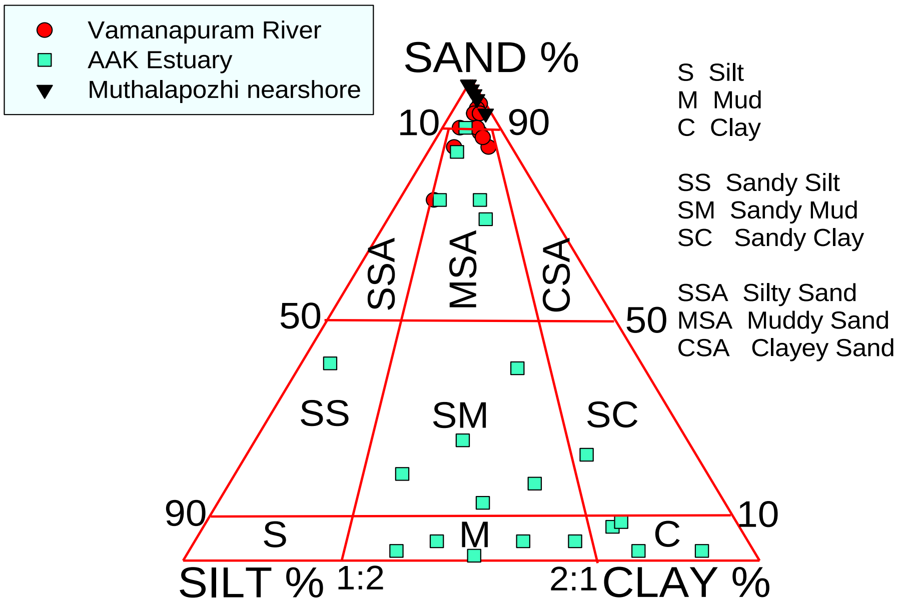


Figure 2. Folk and Ward classification (1957) of surface sediments

Statistical Parameters

Graphic measures from the grain-size analysis of the samples from the three environments are presented in the table 2. The mean size for the Vamanapuram River sediments indicates very coarse sand to very fine sand and shows an increase trend towards the mouth. An abrupt decrease of phi mean in locations V4 and V9 may be accredited to the local turbulence resultant from the presence of boulders and check dam constructed. The average mean size in the estuarine sample is 6.99 ϕ representing very fine sand to clay and in for the nearshore it ranges from medium sand to very fine sand. The standard deviations for the river sediments, in general, are very poorly sorted (54%). There is a slight decrease in standard deviation values as the river flows downstream and a slight increase is noticed when it reaches the estuary. In the estuarine samples 76% of the total studied samples are very poorly sorted and in the nearshore region, the majority of samples show moderately well sorted followed by moderately sorted. The river samples are fine to very fine skewed which ranges between 0.21 and 0.75 (av 0.42) while the estuarine samples skewness varies from - 0.84 – 1.21 (av 0.01). The estuarine samples show equal (38%) portion of very fine skewed and very coarse skewed with a mixture of symmetrical (28%), very coarse skewed and fine skewed (21%) each and 14% of coarse skewed. The skewness of the nearshore sediments ranges from very coarse skewed to very fine skewed. Kurtosis of the river sediments were very leptokurtic and estuarine and nearshore samples are represented by very platykurtic to very leptokurtic distribution. The kurtosis values shows that a maximum number of samples are leptokurtic in nature.

Table 2. Statistical Pa(a) Vamanapuram River (b) AAK estuary (c) Muthalapozhi near shore

(a) Vamanpuram River

	Mean		Sorting		Skewness		Kurtosis		Description
V1	-0.376	very coarse sand	2.052	Very poorly sorted	0.277	Fine skewed	1.12	leptokurtic	muddy sandy gravel
V2	0.587	coarse sand	1.519	Poorly sorted	0.205	Fine skewed	1.87	very leptokurtic	Gravelly sand
V3	0.394	coarse sand	3.077	Very poorly sorted	0.201	Fine skewed	1.43	leptokurtic	muddy sandy gravel
V4	-0.221	very coarse sand	1.943	Poorly sorted	0.278	Fine skewed	1.04	mesokurtic	muddy sandy gravel
V5	-0.367	very coarse sand	1.717	Poorly sorted	0.043	symmetrical	0.73	platykurtic	Sandy gravel
V6	0.379	coarse sand	2.318	Very poorly sorted	0.206	Fine skewed	1.65	very leptokurtic	Gravelly sand
V7	0.574	coarse sand	1.911	Poorly sorted	0.433	Very fine skewed	1.90	very leptokurtic	Gravelly sand
V8	-0.321	very coarse sand	1.493	Poorly sorted	0.397	Very fine skewed	0.78	platykurtic	Sandy gravel
V9	-0.446	very coarse sand	1.747	Poorly sorted	0.525	Very fine skewed	1.33	leptokurtic	muddy sandy gravel
V10	2.089	fine sand	1.879	Poorly sorted	0.488	Very fine skewed	2.83	very leptokurtic	Slightly gravelly sand
V11	0.458	coarse sand	2.282	Very poorly sorted	0.168	Fine skewed	1.84	very leptokurtic	Gravelly muddy sand
V12	3.691	very fine sand	2.564	Very poorly sorted	0.493	Very fine skewed	3.40	extremly leptokurtic	Slightly gravelly muddy sand
V13	0.535	coarse sand	2.468	Very poorly sorted	0.262	Fine skewed	1.60	very leptokurtic	Gravelly muddy sand
V14	2.543	fine sand	1.342	Poorly sorted	0.313	Very fine skewed	1.88	very leptokurtic	Slightly gravelly sand
Average	**0.68**		**2.02**		**0.31**		**1.67**		

(b) AAK estuary

Sample	Mean		Sorting		Skewness		Kurtosis	
K 1	6.79	Medium silt	2.9	Very poorly sorted	0.82	Very fine skewed	0.59	Very Platykurtic
K 2	10.84	Clay	1.4	Poorly sorted	-0.68	Very coarse skewed	2.35	Very Leptokurtic
K 3	9.65	Clay	2.4	Very poorly sorted	-0.72	Very coarse skewed	0.77	platykurtic
K 4	10.53	Clay	1.9	Poorly sorted	-0.73	Very coarse skewed	2.19	Very Leptokurtic
K 5	9.31	Clay	2.9	Very poorly sorted	-0.79	Very coarse skewed	0.69	platykurtic
K 6	9.86	Clay	2.3	Very poorly sorted	-0.76	Very coarse skewed	0.88	platykurtic
K 7	5.23	Coarse silt	3.4	Very poorly sorted	0.68	Very fine skewed	1.14	leptokurtic
K 8	7.03	Fine silt	3.5	Very poorly sorted	0.40	symmetric	0.65	Very Platykurtic
K 9	5.40	Coarse silt	4.2	Extremely poorly sorted	0.46	Very fine skewed	0.52	Very Platykurtic
K 10	5.58	Coarse silt	3.8	Very poorly sorted	0.64	Very fine skewed	0.69	Platykurtic
K 11	3.88	Very fine sand	3.4	Very poorly sorted	0.43	Very fine skewed	1.29	leptokurtic
K 12	2.79	fine sand	2.8	Very poorly sorted	0.73	Very fine skewed	2.60	Very Leptokurtic
K 13	4.16	Very coarse silt	0.9	Moderately sorted	-0.15	coarse skewed	1.24	leptokurtic
K 14	5.90	Coarse silt	3.4	Very poorly sorted	0.78	Very fine skewed	0.82	platykurtic
K 15	7.84	fine silt	3.1	Very poorly sorted	-0.01	symmetric	0.52	Very Platykurtic
K 16	9.66	Clay	2.5	Very poorly sorted	-0.71	Very coarse skewed	0.98	mesokurtic
K 17	9.23	Clay	2.7	Very poorly sorted	-0.53	Very coarse skewed	0.79	platykurtic
K 18	6.68	Medium silt	3.2	Very poorly sorted	0.65	Very fine skewed	0.72	platykurtic
K 19	7.79	fine silt	4.1	Extremely poorly sorted	-0.67	Very coarse skewed	0.54	Very Platykurtic
K 20	7.00	fine silt	3.7	Very poorly sorted	0.07	symmetric	0.49	Very Platykurtic
K 21	7.91	fine silt	3.9	Very poorly sorted	-0.62	Very coarse skewed	0.55	Very Platykurtic
Average	**7.29**		**3.0**		**-0.03**		**1.00**	

(c) Muthalapozhi near shore									
Transect	**Depth**	**Mean**	**Description**	**Sorting**	**Description**	**Skewness**	**Description**	**Kurtosis**	**Description**
M1	Beach	3.31	Very Fine Sand	0.682	Moderately Well Sorted	-0.567	Very Coarse Skewed	1.073	Mesokurtic
	5	1.72	Medium Sand	0.985	Moderately Sorted	-0.020	Symmetric	0.897	Platykurtic
	10	3.73	Very Fine Sand	0.166	Very Well Sorted	0.000	Symmetric	0.738	Platykurtic
	15	2.68	Fine Sand	1.820	Poorly Sorted	0.361	Very Fine Skewed	1.834	Very Leptokurtic
	20	1.28	Medium Sand	0.601	Moderately Well Sorted	0.159	Fine Skewed	1.216	Leptokurtic
M2	5	2.58	Fine Sand	0.694	Moderately Well Sorted	-0.184	Coarse Skewed	0.822	Platykurtic
	10	3.14	Very Fine Sand	0.648	Moderately Well Sorted	-0.056	Symmetrical	0.953	Mesokurtic
	15	1.93	Medium Sand	0.827	Moderately Sorted	0.404	Very Fine Skewed	1.787	Very Leptokurtic
	20	1.27	Medium Sand	0.856	Moderately Sorted	0.236	Fine Skewed	1.670	Very Leptokurtic
M3	Beach	1.45	Medium Sand	0.420	Well Sorted	-0.206	Coarse Skewed	0.888	Platykurtic
	5	2.14	Fine Sand	1.111	Poorly Sorted	0.080	Symmetrical	1.601	Very Leptokurtic
	10	1.32	Medium Sand	0.625	Moderately Well Sorted	0.127	Fine Skewed	1.225	Leptokurtic
	15	3.02	Very Fine Sand	0.980	Moderately Sorted	-0.729	Very Coarse Skewed	0.627	Very Platykurtic
	20	3.43	Very Fine Sand	0.589	Moderately Well Sorted	-0.563	Very Coarse Skewed	1.382	Leptokurtic
Average		**2.36**		**0.79**		**0.07**		**1.19**	

DISCUSSION

A gradual decrease in the grain size along the downstream direction is a prominent feature observed and is mainly due to the differential transport mechanism of the river, which is governed by the variation in mean discharge, speed of water and seasonal variation (Mohan, 1990 and Yasin, 2016). The grain size variation in the Vamanapuram River can be explained by the following process, larger grain rolls faster and further at a long angle of the slope than the smaller particles and the latter will be thrown further in the transporting medium, this gives to differential sorting process and result in polymodal distribution of grains (Brush, 1965 and Taira, and Schoole, 1979). Moreover, sand mining and check dams constructed across the river in many places for groundwater recharge in the Chiranyinkezh Thaluk also restricts the speed of water causing deposition of sediments abruptly. Estuarine hydrodynamics are characterized by complex formation of unsystematic water movement due to the tidal cycle which contributes to a major extent of sediment distribution pattern. The granulometric variations in the AAK estuary demonstrate the multifaceted of the flow pattern prevailing within the estuary. Though coarser fractions encountered in the river sediment are totally missing, a high percentage of sand at the river mouth and inlet are due to the sustainable amount of sand supplied by the river and the winnowing action of the wave. The percentage of sand reported for near-shore sediments is in concordance with the reported data from Adimalathura to Kovalam (90 to 99.7%) which is situated further south of the present study area (Silpa et al., 2019). The difference in grain size observed from north to south transect of the study area is attributed to the presence of varying morphological features and the difference in the hydrodynamic conditions of the area (Prasad et al., 2019). Steep bathymetry and winnowing action of waves along with long shore currents flowing towards the north remove finer fractions. Earlier it was reported that Poovar - Varkala sector is a high energy coast and shows steep gradient with medium size grains and Neduganda which falls in the shadow region of the Varkala Cliff region have calm environment (Silpa et al., 2017). Similarly, the wave energy regime exhibits the highest energy for off Thiruvananthapuram region with steep gradient for the nearshore bathymetry and medium-size sediments (Baba and Kurian, 1988 and Thomas, and M. Baba, 1986].

The downstream decrease in grain size or increase in phi mean is resulted due to the simultaneous action of transportation and abrasion (Pettijohn, 1984). Whenever the ability of the river to transport its load declines, coarser sediments are deposited and finer ones are carried further downstream (Mir, and Jeelani , 2015). However, it is understood that the fluctuation in the competency of the river due to factors like the seasonal discharge variation, physiography, fluvial morphology, etc also brings about a decrease in the mean size of the sediments (Maya, 2005). This dissimilarity in mean size specify the differential energy condition of river along its transporting path which may be influenced by the source of the sediment, its transporting medium and the energy condition of the depositional environment (Kumar, 2010). A considerable increase in the mean size of the estuarine samples than that of the river may be due to the high percentage of silt and clay. However, at the juncture where the river enters the estuary and at the inlet the mean size is considerably low. The lower mean size in the mouth region may be attributed to the constant wave and tidal action that carry away the finer particles offshore leaving behind the coarser. Also, the river current loses its energy while entering the estuary, the variation in salinity, increase of depth and constant resistance offered by the waves also causes the sudden deposition of coarser sediments. A similar pattern was noticed by (Mohan, 1990 and Hegde, 2004) in their respective studies. The variations in the mean size of the sediments in the nearshore reveal the differential energy conditions, resulting in their deposition (Sahu, 1964 and Bhattacharya, 2016). Transition zones from the finer phi values to coarser phi values demarcate the mixed sediment size grade. The sediments that have >90% of sand suggests the relict nature of the sediment, probably the part of the palaeo shoreline. The presence of relict sediments at seaward stations of the inner shelf region suggests the modern detrital sediments from land that are probably trapped by the estuary thereby detrital sediments that escape from these marginal bodies may spread as a continuous blanket across the inner shelf. A similar study was reported for the southern east coast of India by (Angusamy and Rajamanickam, 2006).

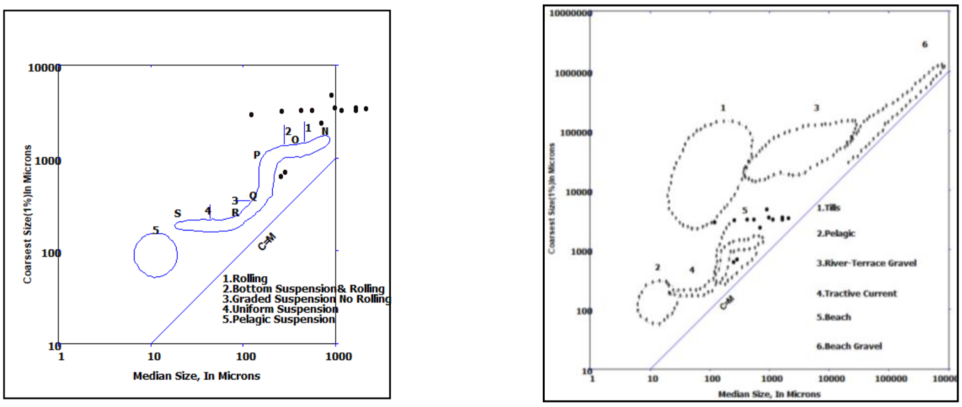
The poor sorting and mean value in the river manifest nearness to the source and a reduced amount of transport of the sediments (Joseph et al., 1997). The presence of poorly sorted sediments in the estuary may be due to the mixing of two or three modes in equal amounts. By the continuous addition of finer and coarser particles in varying proportions along with the lesser energy condition in the estuary acts as a trap for the sediments which prevent effective sorting. A similar condition was reported for the Vellar Estuary (Mohan, 1990) and in Gosthani River - Estuary, Andhra Pradesh (Ganesh, 2013). The estuarine sediments are characterised by finer particles which are poorly sorted. This suggests the presence of sheltered conditions within the estuary which facilitated the accumulation of fine sediments, and passive physical processes in these locations (Ganesh, 2013). Also the dominance of silt can be attributed to the mixing of saline and fresh water resulting in the reduction of energy of the depositional media as well as flocculation and settling of suspended matter (Pejrup,1988 and Hegde, 2004). Similar features were reported at the Sharavati Estuary (Hegde, 2004) and Cochin Harbour (Nair et al., 1993). The prevalence of moderately well-sorted sediment in the nearshore samples reveals the continuous reworking of sediments by the winnowing or back and forth movement of water from the breaking waves (Srinivasa Rao, 1990 and Suganraj, 2013). Further the occurrence of moderately and moderately well-sorted sediments with high sand content, characteristics of the beach environment and also the presence of relict sand in the form of paleo shoreline. The variations in the sorting values are likely due to the continuous addition of finer/coarser materials in varying proportions. A considerable number of poorly sorted sediments stipulate near source region.

Positive skewness of the Vamanapuram River is due to the presence of fine sediments due to the competency of the unidirectional flow of the transporting media where the coarse end of the size-frequency curve is chopped off, resulting the accumulation in sheltered environments while negative skewness is caused by the amputation of the fine-grained end of the curve due to the winnowing action (Rajasekhara, 2008 and Mir, and Jeelani, 2015). The sediments in the upstream portion are fine skewed and when it reaches the midland the fine mode increases and the skewness shifts to fine. The presence of symmetrical skewed sample in (V5) may be due to the equal portion of different modes. The estuarine sediment show varying energy condition with in estuary as evident from the skewness. Very fine skewed to fine skewed sediments generally imply the introduction of fine material by riverine input (Ganesh, 2013). This is clearly evident from the locations K7 to K12 where the Vamanapuram River debouches into the estuary. In general, most beach sediments are slightly negatively skewed since a small proportion of coarse grains always accompanies. Negatively skewed sediments are affected by higher energy depositing agents and are subjected to transportation for a greater length of time, or the velocity fluctuation toward the higher values occurred more often than normal (Sahu, 1964). Positive skewness of sediments indicates the deposition of the sediments in sheltered low energy, whereas negative skewed sediments indicate deposition at high energy environments (Rajasekhara et al., 2008). The major part of the inner shelf is carpeted with negatively skewed sediments. It is confined to the near shore and offshore stations, which support the high energy conditions where the fines are removed by winnowing action of waves and currents. Symmetrical sediments are also noticed for certain samples showing the possibility of the absence of extreme conditions like a wave breaking tidal variations and seasonal supply of detrital materials in equal proportions of different modes. As explained by (Friedman, 1967) the distribution of present-day beach sand is negatively skewed or symmetrical.

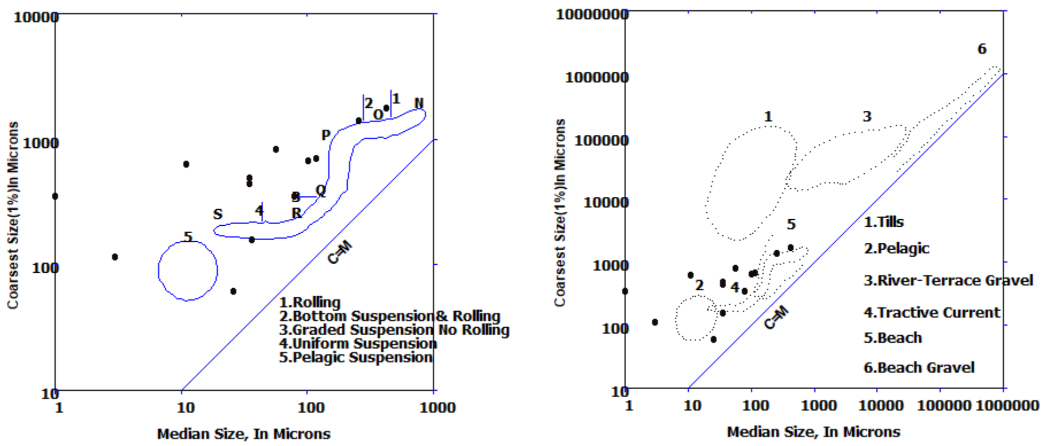
The kurtosis values replicate discrepancy in the velocity of the depositing medium and it is considered that for normal distribution the kurtosis is unity. Values greater than unity suggest the velocity of fluctuations were restricted within the central 50% of the average velocity and it reflects greater fluctuations in the energy conditions of the depositing medium (Verma, and C. Prasad, 1981). The river sediments represent leptokurtic nature indicate high deposition due to the variation in sorting owed due to the continuous addition of finer/coarser material in varying portions (Mir, and Jeelani, 2015). The dominance of finer size and platykurtic nature of the estuarine sediments reflects the maturity of the sediment grains. The variation in the kurtosis values is a reflection of the flow characteristics of the depositing medium (Seralathan, and Padmalal, 1994 and Karuna Karudu, 2013). In the near shore area, negative skewness leptokurtic sediments occur 50% and platykurtic (35%) occurs in with a few mesokurtic sediments. Apparently, the kurtosis values indicate that the majority of samples contain a wide range of sediment sizes with sub equal proportions of different size classes. Variation in kurtosis reflects flow characteristics depending on the medium and size of sand, aggregation of material due to density (Viveganandan et al., 2013 and Friedman, 1962) suggested that extremely high or low values of kurtosis imply that part of the sediment achieved its sorting elsewhere in a high energy environment.

CM Pattern

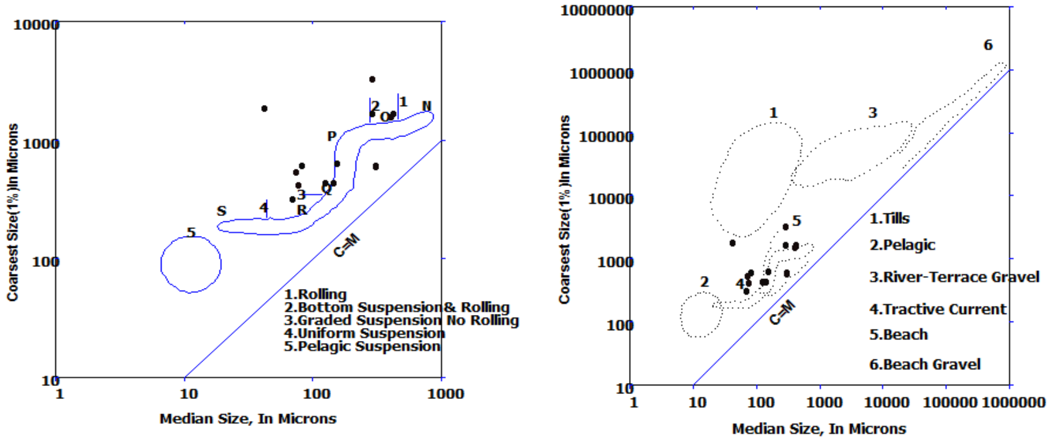
Majority of the samples in the upper reaches especially sediments having a low percentage of clay show marked a deviation from the standard segments in the CM pattern (fig 3). The CM pattern worked out for the river samples reveal that they are transported and deposited under rolling and bottom suspension and rolling under tractive and beach deposits. Most of the sediments fall in the segment between N and O which represents the coarsest bed load materials which are larger than 2000 microns of C. The rolling mode of transportation takes place in the gravel-rich sediments and this occurs due to the competency of the river due to their high gradient. The estuarine sediments falls in PQ to RS sector which indicate graded suspension with no rolling to uniform suspension. The sediments are transported under tractive current. These designate the change in hydrodynamic condition and comparatively more percentage of mud particles in the estuarine sediments. The CM plot for the Muthalapozhi near-shore shows that most of the sediment samples fall in the intermediate position between O and R. The OR segment exhibits that the Muthalapozhi nearshore sediments underwent the bottom suspension and rolling and graded suspension. The plots occupy the zone of tractive current and beach deposits.



(a)



(b)



(c)

Figure 3. CM Pattern of surface sediments (a) Vamanapuram River (b) AAK estuary and (c) Muthalapozhi nearshore

Hydrodynamic Condition

Ternary diagram has been used to decipher the hydrodynamic condition prevailing in the three depositional environment in the study area (fig 4). River shows more than 65% of sand which are deposited in low to very high energy condition in accordance with the competency of the river. But in the estuarine environment, the hydrodynamic condition mostly concentrated in moderate to high condition and only one sample falls in the very high energy condition which is due to the inlet where the high tidal activity takes place. Energy condition again increases as the sediments reach the nearshore where the finer particles are removed and sand particles concentrate. Sediments in the nearshore show more than 90% of sand which is deposited in very high energy conditions.

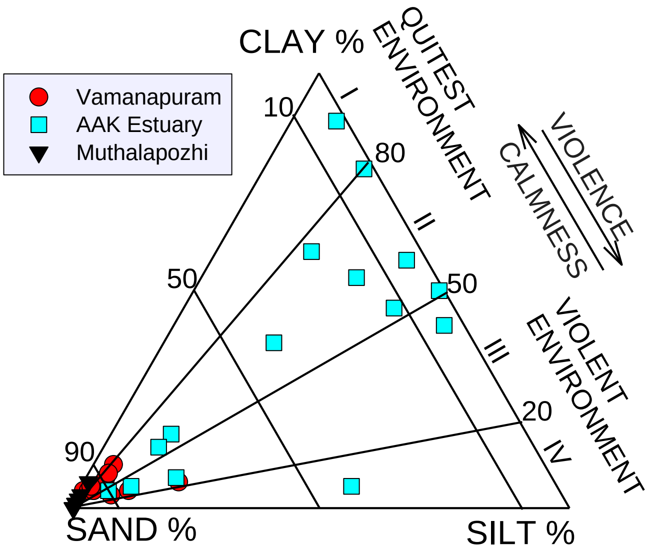


Figure 4. Hydrodynamic condition of surface sediments

From the river prolonged downstream bed load transport of sediment occurs which may be inhibited naturally by the bed and banks of the river and anthropogenically be sand mining in the area, there by delivering small quantities of sand into the estuary. However during monsoon seasons energy condition increases and high flow carries large quantities of sand into the estuary. The presence of very fine sand at river mouth (K11) is the evidence for some energy and sediment exchange between the river and estuary. Also very coarse silt evident in the estuary (K13) and fine sand in M_2 transect at 5cm depth in the nearshore suggests that energy exchange between the sub environment are active. Within the estuary, tidal currents along with other energies operate in selective sorting, winnowing and transporting material thereby maintaining estuary-beach sediment exchange. The grain size distributions of the nearshore indicate high energy environment and seaward source for the sediments with small contribution from the river and estuary. Similar grain size statics was used to explain estuarine - beach interaction in the Hayle estuary and St Ives bay of southwest England (Oyedotun, 2016).

Linear Discrimination Function

The LDF values calculated for the studied sediments are presented in (Table 3and figure 5). All the samples of the river were deposited under the beach and shallow agitated process with respect to Y1 and Y2 values and under fluvial (deltaic) environment with reference to Y3 values. According to Y4 values, 64% of samples were deposited under the turbid environment. 76 % of the estuarine samples are deposited under beach process and all samples were deposited in shallow agitated water with reference to Y1 and Y2. 95% of samples falls under the fluvial (deltaic) environment with respect to Y3 values while 80% showed turbid environment. The results indicate that the river sediments were deposited in the shallow agitated fluvial (deltaic) environment and estuarine sediments were derived from both fluvial (sediments discharged by rivers) and marine environments. For the Muthalapozhi nearshore region, 57% of the samples have Y1 values that are greater than -2.74 which imply the beach environment and rest in the aeolian process. The discrimination between the beach and shallow agitated marine environment (Y2) imply all samples are shallow agitated marine environment. Further, the values for Y3 exhibits the fluvial (deltaic) and shallow marine condition of deposition. The linear discriminate function at the present study shows that about 90 % of samples were deposited by turbidity process and 10 % of samples by fluvial action. The sediments deposited in this region are mainly by wave action. It can be inferred that the sediments in the present-day beaches must have been deposited in a shallow marine environment and marine deterioration must have led to the development of the present-day shorelines.

Table 3. LDF values of the surface sediments from Vamanapuram River, AAK Estuary and Muthalapozhi Nearshore

(a) Vamanapuram River								
Sample No	Y1	Remarks-Y1	Y2	Remarks-Y2	Y3	Remarks-Y3	Y4	Remarks-Y4
V2	16.78	Beach	218.88	Sh. Agitated water	-28.19	Fluvial (deltaic)	11.11	Fluvial (deltaic)
V3	20.64	Beach	333.27	Sh. Agitated water	-41.12	Fluvial (deltaic)	8.38	turbidity
V4	17.49	Beach	255.93	Sh. Agitated water	-32.54	Fluvial (deltaic)	9.66	turbidity
V5	33.25	Beach	568.42	Sh. Agitated water	-72.69	Fluvial (deltaic)	5.82	turbidity
V6	25.73	Beach	522.77	Sh. Agitated water	-59.27	Fluvial (deltaic)	13.80	Fluvial (deltaic)
V7	15.26	Beach	264.53	Sh. Agitated water	-29.67	Fluvial (deltaic)	12.00	Fluvial (deltaic)
V8	20.98	Beach	334.60	Sh. Agitated water	-41.00	Fluvial (deltaic)	11.36	Fluvial (deltaic)
V9	26.60	Beach	310.31	Sh. Agitated water	-34.58	Fluvial (deltaic)	21.34	Fluvial (deltaic)
V10	16.86	Beach	376.16	Sh. Agitated water	-38.44	Fluvial (deltaic)	21.28	Fluvial (deltaic)
V11	20.37	Beach	359.25	Sh. Agitated water	-40.44	Fluvial (deltaic)	13.50	Fluvial (deltaic)
V12	15.83	Beach	391.33	Sh. Agitated water	-40.20	Fluvial (deltaic)	22.18	Fluvial (deltaic)
V13	34.31	Beach	651.91	Sh. Agitated water	-80.39	Fluvial (deltaic)	8.18	turbidity
V14	21.30	Beach	554.36	Sh. Agitated water	-61.28	Fluvial (deltaic)	13.51	Fluvial (deltaic)

(b) AAK Estuary								
Sample No	**Y1**	**Remarks-Y1**	**Y2**	**Remarks-Y2**	**Y3**	**Remarks-Y3**	**Y4**	**Remarks-Y4**
K1	-7.87	Aeolian	520.97	Shallow Agitated	-46.96	Fluvial (deltaic)	5.85	Turbidity
K2	-49.26	Aeolian	131.48	Shallow Agitated	-3.69	Shallow marine	-0.96	Turbidity
K3	-10.38	Aeolian	500.09	Shallow Agitated	-35.26	Fluvial (deltaic)	11.12	Fluvial (deltaic)
K4	25.69	Beach	1058.43	Shallow Agitated	-117.21	Fluvial (deltaic)	-1.79	Turbidity
K5	6.79	Beach	708.19	Shallow Agitated	-76.84	Fluvial (deltaic)	7.3	Turbidity
K6	-1.35	Beach	639.12	Shallow Agitated	-60.53	Fluvial (deltaic)	2.55	Turbidity
K7	9.07	Beach	379.62	Shallow Agitated	-36.49	Fluvial (deltaic)	17.61	Fluvial (deltaic)
K8	30.81	Beach	994.3	Shallow Agitated	-116.57	Fluvial (deltaic)	1.43	Turbidity
K9	2.55	Beach	265.86	Shallow Agitated	-23.94	Fluvial (deltaic)	3.83	Turbidity
K10	11.98	Beach	260.04	Shallow Agitated	-25.24	Fluvial (deltaic)	19.06	Fluvial (deltaic)
K11	42.9	Beach	1080	Shallow Agitated	-133.44	Fluvial (deltaic)	7.3	Turbidity
K12	12.44	Beach	835.1	Shallow Agitated	-88.71	Fluvial (deltaic)	1.68	Turbidity
K13	7.88	Beach	280.74	Shallow Agitated	-23.45	Fluvial (deltaic)	17.58	Fluvial (deltaic)
K14	20.78	Beach	649.25	Shallow Agitated	-65.91	Fluvial (deltaic)	27.78	Fluvial (deltaic)
K15	7.61	Beach	739.19	Shallow Agitated	-78.01	Fluvial (deltaic)	4.13	Turbidity
K16	7.34	Beach	697.78	Shallow Agitated	-77.54	Fluvial (deltaic)	9.38	Turbidity
K17	-8.35	Aeolian	544.09	Shallow Agitated	-46	Fluvial (deltaic)	4.59	Turbidity
K18	-8.34	Aeolian	555.74	Shallow Agitated	-45.44	Fluvial (deltaic)	6.22	Turbidity
K19	-8.97	Aeolian	546.93	Shallow Agitated	-43.79	Fluvial (deltaic)	7.03	Turbidity
K20	19.55	Beach	874.74	Shallow Agitated	-100.61	Fluvial (deltaic)	7.42	Turbidity
K21	23.99	Beach	902.45	Shallow Agitated	-104.32	Fluvial (deltaic)	3.95	Turbidity

(c) Muthalapozhi Nearshore									
Sample No	**Depth**	**Y1**	**Remarks Y1**	**Y2**	**Remarks-Y2**	**Y3**	**Remarks-Y3**	**Y4**	**Remarks-Y4**
M1	Beach	-5.580	Aeolian	91.995	Shallow Agitated	-0.304	Shallow Marine	4.064	Turbidity
	5	0.280	Beach	106.944	Shallow Agitated	-7.867	Fluvial (deltaic)	5.464	Turbidity
	10	-10.898	Aeolian	73.791	Shallow Agitated	0.857	Shallow Marine	6.583	Turbidity
	15	7.664	Beach	300.048	Shallow Agitated	-29.932	Fluvial (deltaic)	12.734	Fluvial (deltaic)
	20	0.214	Beach	69.198	Shallow Agitated	-3.518	Shallow Marine	8.286	Turbidity
M2	5	-4.494	Aeolian	83.959	Shallow Agitated	-2.543	Shallow Marine	4.781	Turbidity
	10	-6.558	Aeolian	93.317	Shallow Agitated	-2.464	Shallow Marine	6.761	Turbidity
	15	0.354	Beach	115.596	Shallow Agitated	-7.331	Shallow Marine	13.298	Fluvial (deltaic)
	20	2.900	Beach	103.156	Shallow Agitated	-7.132	Shallow Marine	11.046	Fluvial (deltaic)
M3	Beach	-1.340	Beach	47.037	Beach	-0.080	Shallow Marine	4.290	Turbidity
	5	1.743	Beach	145.710	Sh. Agitated water	-10.517	Fluvial (deltaic)	10.060	Fluvial (deltaic)
	10	0.285	Beach	71.297	Sh. Agitated water	-3.608	Shallow Marine	8.134	Turbidity
	15	-3.771	Aeolian	108.845	Sh. Agitated water	-3.954	Shallow Marine	0.206	Turbidity
	20	-5.474	Aeolian	91.819	Sh. Agitated water	0.760	Shallow Marine	5.857	Turbidity

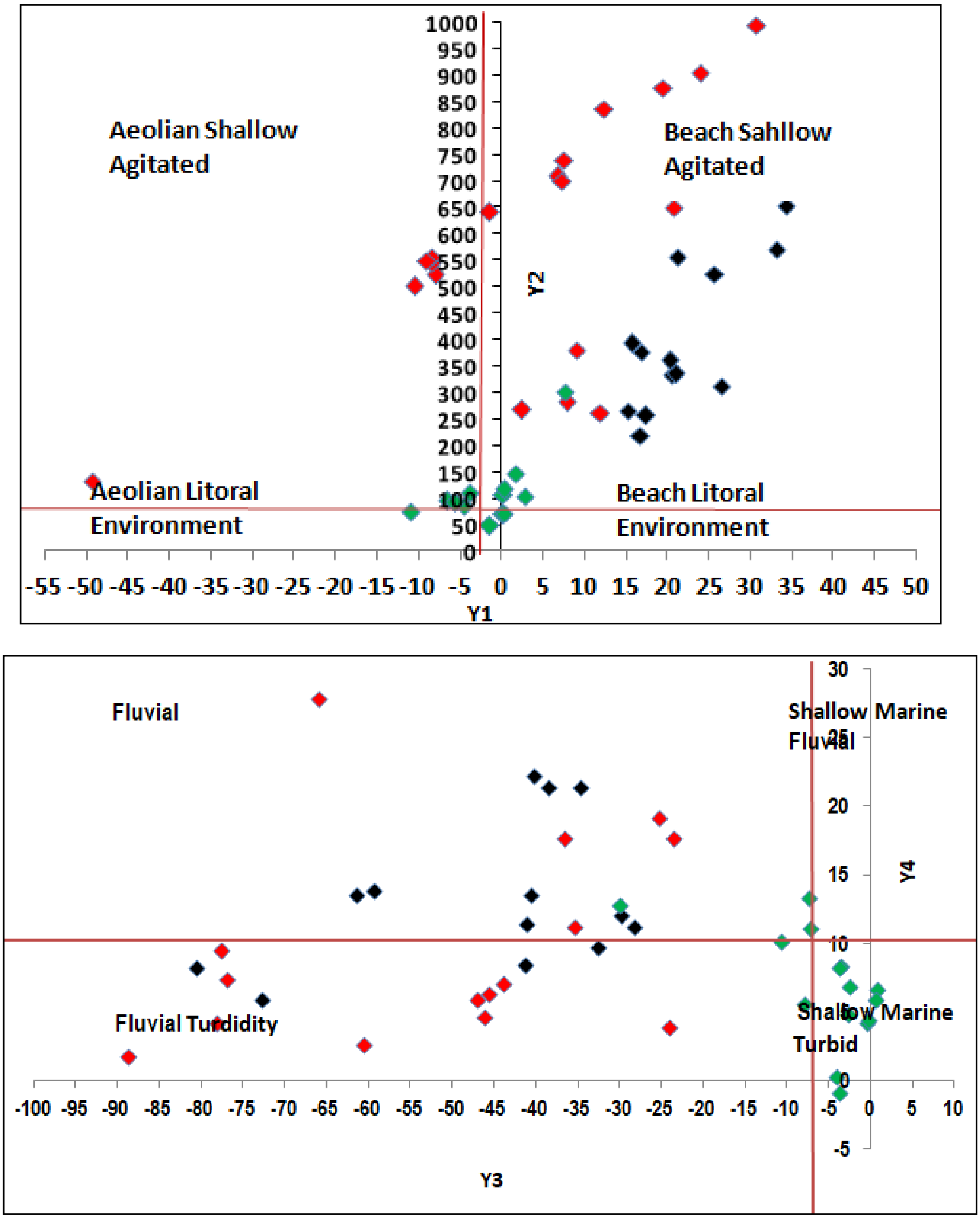


Figure 5. LDF values of the surface sediments from Vamanapuram River ◆ , AAK Estuary ◆ and Muthalapozhi Nearshore ◆

CONCLUSION

The sediment samples of the Vamanapuram River exhibits a scale of particle sizes series from pebbles to mud and a gradual decrease in the grain size along the downstream direction following the competency of the river. The sediments were poorly sorted, fine skewed and leptokurtic indicating nearness to the source and a reduced amount of transport for the river sediments. The estuarine floor is carpeted by mud which is very poorly sorted. Skewness and kurtosis indicate varying energy condition in the estuary that prevents effective sorting and the domination of platykurtic nature reflects the maturity of sand. In the nearshore area, the prevalence of moderately well-sorted sediment with high sand content reveals the continuous reworking and also the presence of relict sand in the form of paleo shoreline. The kurtosis values mark a wide range of sediment sizes with subequal proportions of different size classes which reflects the flow characteristics and high energy environment. Most of the sediments are transported by rolling to bottom suspension under tractive current while the estuarine sample showed graded suspension with no rolling to uniform suspension under tractive current. Sediments underwent bottom suspension and rolling and graded suspension in nearshore as indicated by CM pattern. LDF values for river show that river sediments were deposited under the beach and shallow agitated process under fluvial (deltaic) environment. Estuarine samples are deposited under beach process, shallow agitated water under the fluvial (deltaic) environment with a turbid environment. The nearshore sediments are deposited under beach and shallow agitated marine environment by turbidity process. Hydrodynamics condition for the river show low to very high energy indicating varying competency of the river and the estuarine environment mostly concentrated in moderate to high condition while the nearshore indicated very high energy condition. The study concludes that the transportation and depositional processes of the surface sediments from its source (Western Ghats) to sink (Arabian Sea) is controlled by the hydrodynamic process operating in these sub environments.

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